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Latitudinal variation of the intensity of 5577Å line of night airglow

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The latitudinal variation of the integrated emission of 5577Å line intensity in the night airglow is calculated assuming that the emission originates from the 95-105 Km layer by the Chapman's mechanism, namely,

$$O+O+O \rightarrow O_2+O(^1S_0)$$

The intensities are calculated for the latitude range extending from 60°N and 60°S at intervals of 10°. Quenching of $O(^1S)$ atoms due to collisional deactivation by atmospheric constituents are considered. To differentiate the seasonal effect from the latitudinal variation of intensity, calculations have been made for different seasons, namely, spring, summer and winter.

The theoretical curves are compared with those observed during shipboard and airborne observations. The observed and calculated curves agree with each other for different seasons.

1. INTRODUCTION

Photometric observations of the latitudinal variations of the intensity of 5577Å line of night airglow were carried out by various observers. Nakamura (1959) made this observation during Soya Voyage in October 1957, Davis & Smith (1965) during Eltanin Voyage from May to November 1962, Markham (1967) from the jet aircraft from January to April, 1964 and Greenspan & Woodman (1967) during Croatan Voyage from February to May 1965 Nakamura (1959) and Markham (1967) made measurements in the 40°N to 20°N latitude range and observed maximum intensity at about 30°N The observations carried during the Eltanin and Croatan voyages extended over a greater latitude range from 35°N to 60°S The intensity curve exhibited symmetry around the geographic equator with maxima at 30° in both hemispheres. Besides agreeing with the latitude for intensity maxima all these observations show a definite pattern of intensity variation of 5577Å line with latitude No theoretical interpretation of the latitudinal variation of 5577Å line intensity is available

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2. Method of Calculation

To diffrentiate the seasonal effect from the latitudinal variation of intensity, calculations have been made for different seasons The year is divided into three seasons—February–May (spring), June–September (summer) and October–January (winter). Each set of calculations corresponds to the mean value during a particular season

2.1 *Expression for Integrates Intensity*

For calculating the latitudinal variation of 5577Å line intensity it has been assumed that this emission originates from 100 Km level by the Chapman's mechanism, namely

$$0+0+0 \xrightarrow{k} 0_2+0(^1S_0)$$

Let $n_z(0)$ be the number density of oxygen atoms at an altitude z within the airglow layer The number of excited $0(^1S)$ atoms produced is $n_z(0)^3k$ per c c The removal of $0(^1S)$ atoms depends on the following ·

(1)The number of $0(^1S)$ atoms that can be removed due to the transition from $^1S_0$ to $^1D_2$ state and subsequent emission of the 5577°A line is given by $n_z(^10_2)\ A_{5577}$, where $n_z(^10_s)$ is the number density of $0(^1S_0)$ at the altitude z and A_{5577} is the transition probability of $^1S_0-^1D_2$ transition

(2) The number of $0(^1S)$ atoms that can be removed due to quenching is given by $n_z(^10_s)q_x n_z(x)$ where q_x denotes the quenching coefficient and $n_z(x)$ is the number density of the quenching constituent X at the altitude Z.

The emission from a column of 1 sq cm cross-section and 1 Km length at an altitude z is given by

$$\Delta I_z = A_{5577}n_z(^10_s)$$

$$= \frac{A_{5577}kn_z(0)^3 10^5}{A_{5577}+\sum_x q_x n_z(x)}$$

Hence, the integrated emission from a layer extending over altitude from z_1 to z_2 is given by

$$I = \sum_{z_1}^{z_2} \Delta I_z$$

$$= A_{5577}K \sum_{z=z_1}^{z_2} \frac{n_z(0)^3 10^5}{A_{5577}+\sum_x q_x n_z(X)}$$

The emission is assumed to be emitted for a layer 10 Km (Baker *et al* 1967) thick extending from 95 Km to 105 Km altitude. The rate of emission is calculated for the latitude interval 60°N to 60°S in steps of 10°.

2.2 *Calculation of Number Density*

Reference densities at 60°N and 30°N during winter and summer for 95 Km to 105 Km altitude range are obtained from idealised curves for mean seasonal and latitudinal variations for 80 to 120 Km altitude range (Champion 1966). The spring densities are assumed to be the mean of summer and winter values. Due to the non-availability of data of percentage deviation of density from the reference values at 60°N and 30°N for the above altitude range, the percentage deviation at 80 Km given in Cospar International Reference Atmosphere (1965) is considered and is used to obtain the densities of 60°N to 0°. For the southern hemisphere the density deviations are considered at an interval of six months. During summer in northern hemisphere, winter reference values in the southern hemisphere are considered and vice versa. The equatorial density is taken to be the mean of the two values obtained from calculations of both hemispheres Mean percentage deviation over four months during each season—is considered and is used to obtain the average density for the season Thus for each of the three seasons, densities from 95 to 105 Km at an interval of 1 Km are obtained for intervals of 10° latitude from 60°N through 60°S.

To obtain the number density of oxygen atoms, the ratio $n(0)/\rho$ from Cospar International Reference Atmosphere (1965) is referred for each altitude and the number density is obtained from the calculated values of density. It should be noted that the density of atomic oxygen obtained from Cospar International Reference Atmosphere (1965) is of the order of 10^{11} particles/cm^3 Young & Black (1966) estimated an upper limit of 10^{-34} cm^6/sec for rate coefficient of Chapman's mechanism It is seen that even with this upper limit for the rate coefficient, if the airglow emission intensity is extimated considering the above number density, it falls short from the observed value by one order On the other hand Young (1969) predicted the density of atomic oxygen around 100 Km to be 10^{12} particles/cm^3 With this value of $n(0)$ and a mean value of 2.5×10^{-35} cm^6/sec for the rate coefficient, the calculated value of the intensity agrees with the observed values Hence after obtaining the number density of atomic oxygen from the $n(0)/\rho$ ratio given in Cospar International Reference Atmosphere and the estimated value of density, it is corrected by a factor of five to obtain the $n(0)$ of the 10^{12} order

Quenching of $O(^1S)$ *atoms*

Quenching of $O(^1S)$ atoms due to collisional deactivation by atmospheric constituents are considered Removal rate coefficients for quenching of $O(^1S)$ atoms by atmospheric constituents given by Stuhl & Welge (1969) are shown in Table 1.

The effect of all constituents other than O_2 and N_2 molecules are negligible due to their low abundance at 100 Km altitude. Since the density of each of

Table 1. Quenching of $O(^1S)$ atoms by atmospheric constituents given by Stuhl & Welge (1969)

Gas	$O(^1S)$ quenching rate coefficient ($cm^3\ sec^{-1}$)
O_2	5×10^{-13}
N_2	$\lesssim 10^{-16}$
NO	5.5×10^{-10}
N_2O	1.6×10^{-11}
N_2	1×10^{-15}

these molecules is of the order 10^{12} particles/cm^3, quenching due to N_2 can be neglected compared to that of O_2, because the quenching rate coefficient for N_2 is three orders less than that for O_2. The number density of O_2 is obtained at each altitude from the ratio $n(O_2)/\rho$ given in Cospar International Reference Atmosphere and the calculated values of density. From these values, $qn(O_2)$, the probability of quenching $O(^1S)$ atoms by O_2 is calculated.

The probability for $O[(^1S_0-^1D_2)$ transition for 5577Å line emission is determined in the laboratory by McCorkey & Kernehen (1968) and is reported to be $1.3\pm.4\ sec^{-1}$. This value is used in the calculations.

The emission from each kilometer thick layer of the atmosphere calculated from 95 Km to 105 Km and the integrated emission of 5577Å line is obtained for each latitude at different seasons.

3 Results

The calculated integrated emissions (in rayleigh) from 95-105 Km layer is given in table 2.

Spring Season

The intensity curve for spring (figure 1) shows that there is a maximum around 20°S. In the northern hemisphere at about the same latitude there appears to have a maximum. Another maximum is observed at 50°N after attaining a minimum at about 40°N. No such variation is observed in the southern hemisphere. In between the two maxima at 20°N and 20°S there is a minimum at 10°S. The general level of intensity is about 100R.

Winter Season

The winter intensity curve shown in figure 2 exhibits higher values of absolute intensity and its variation in the northern hemisphere. This results because the reference values of density taken from Champion (1966) are higher for winter than for summer. For this season, calculations for southern hemisphere were made assuming summer values. In the northern hemisphere there is a maximum in the 10-20° region. Whereas in the southern hemisphere there is a minimum at 40° region A pronounced maximum is seen at 50°N, whereas there is a minimum at 50°S

Table 2. Calculated integrated 5577Å line intensity

Latitude	Spring (Feb.–May)	Summer (June–Sept.)	Winter (Oct.–Jan)
60°N	214.2	97.9	400.9
50°N	256.1	47.4	621.0
40°N	172.1	209.2	204.0
30°N	188.1	140.0	306.6
20°N	245.4	130.6	361.5
20°N	245.4	130.6	316.5
10°N	244.5	104.0	376.6
0°	233.8	109.1	245.3
10°S	225.9	332.3	138.8
20°S	259.9	[illegible]34.4	132.3
30°S	221.8	273.2	149.1
40°S	211.3	208.7	171.1
50°S	214.3	224.9	70.0
60°S	214.3	400.8	95.3

The intensity is expressed in rayleigh.

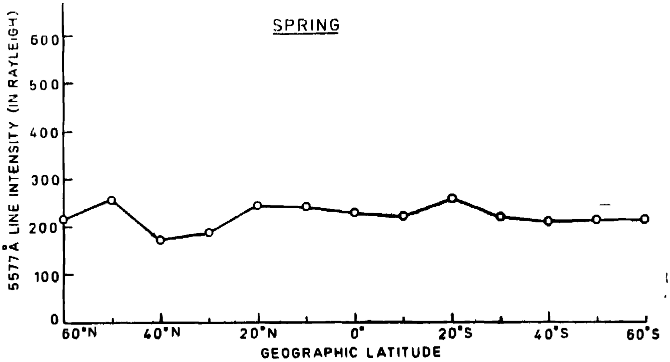

Fig 1 The variation of the intensity of 5577Å line for spring with respect to geographical latitude calculated assuming that the airglow originates from 95-105 Km altitude layer and by Chapman mechanism.

Summer Season

During summer the intensity of 5577Å line emission in the southern hemisphere is greater (figure 3) This is because winter values of density are considered for this hemisphere. The maxima are at 40°N and 10-20°S. Beyond 50° the intensity increases in both hemispheres. Thus the intensity variations of 5577Å line for the summer season correspond roughly to those for winter with the hemispheres interchanged

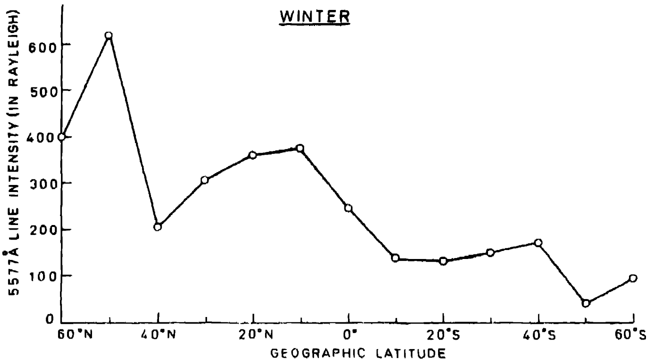

Fig. 2. The variation of the intensity of 5577Å line for winter with respect to geographical latitude calculated assuming that the airglow originates from 95-105 Km altitude layer and by Chapman mechanism

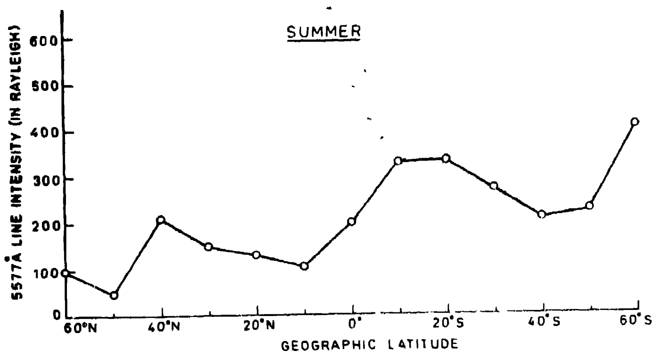

Fig. 3. The variation of intensity of 5577Å line for summer with respect to geographical latitude calculated assuming that the airglow originates from 95-105 Km altitude layer and by Chapman mechanism.

4. Comparison of Calculated and Observed Intensities

The theoretical curve for the spring season agrees in general with the shipboard observations and airborne observations The theoretical curve and that obtained during Croatan Voyage both show maxima in the 20-30° latitude range on both sides of the geographic equator The minima in the equatorial region for both curves are situated in the southern region Only the equatorial dip is not so pronounced in the theoretical curve. The steep increment in the observed value beyond 40°S may be considered as due to the onset of summer when the intensity increases for 250R to 400R (see figure 4) Markham's jet flight data

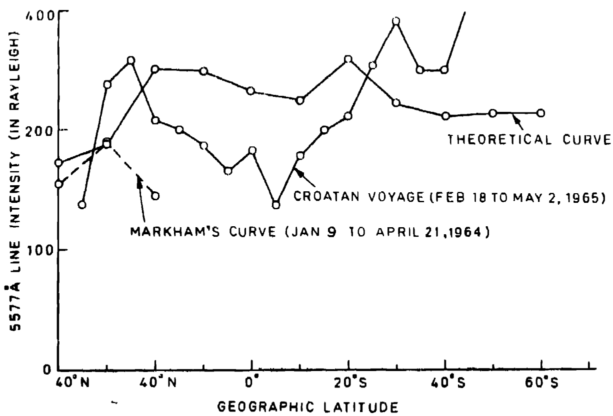

Fig. 4. The theoretical and observed latitudinal variations of 5577Å line intensity for spring Note that the theoretical curve agrees in general with the shipboard observations (Croatan Voyage) and the airborne observations by Markham

show a maximum in the same region as in other curve, although the general level of intensity is less. This may be due to the fact, that his observations were taken nearer to the IQSY period

During the Eltanin Voyage observations were taken for 7 months from spring to winter (figure 5). Hence the data are not expected to fit with a single theoretical curve Portions of the curve fits with the theoretical curve for the appropriate period The ship Eltanin departed from New York in May 1962 and arrived Valparaiso, Chile in the next month. This being the spring-summer season, the observed intensity shows excellent agreement with the theoretical spring data over the northern latitude 40-10°N For the period July to November the Eltanin made several cruises southward from Valparaiso and observations were obtained for 36 nights The theoretical winter data fits with the observed intensities for the region 20°-60°S. As no data is taken at 50°S on this voyage the dip cannot be matched.

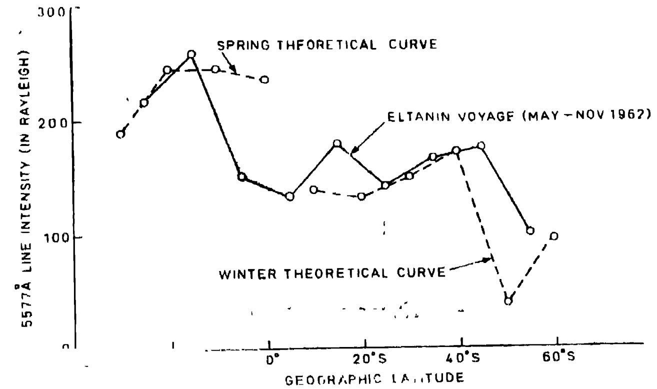

Fig. 5. Comparison of the theoretical curves of 5577Å line intensity for spring and winter with that obtained during the Eltanin Voyage Note that these is fair agreements between the theoretical and observed curves

5. Concluding Remarks

The observed and calculated curves obtained from assuming Chapman's mechanism shows the following :

(1) A general agreement between the observed and the calculated curves.

(2) A noticable variation of the latitudinal distribution of the intensity of 5577Å line emission with season.

The calculated intensity can however be improved if the percentage deviations of density at different latitudes are available for the 95-105 Km altitude range In the absence of these data, the percentage deviation of density of different latitudes for 80 Km is assumed for the above altitude range.

The characteristics of the observed and calculated intensity variation with latitude is given in table 3.

Table 3 Characteristic features of latitudinal variation of 5577Å line intensity

Season	Max. at high N. Lat.	Minimum at N. lat	Max. at low N. Lat.	Minimum in equatorial region	Max. at low S. lat.	Minimum at S. Lat	Max at high S. lat	Remarks
Spring								
From calculated curve	50°N	40°N	20°N (tends to a max)	10°S	20°S	40°S	No change upto 60°S	The observed and calculated curves show
From Croatan Voyage	—	At 35°N Low value	25°N (sharp)	5°S	30°S (sharp)	35e–40eS	Steep rise after 40°S	(1) maximum at low northern latitudes
From Markham's jet flight	—	At 40°N Low value	30°N	—	—	—	—	(2) minimum in the equitorial region and
From Eltanin Voyage	—	At 30°N low value	15°N	5°S	—	—	—	(3) low southern latitude maximum
Summer								
From calculated curve	Shows increment in 50-60N	50°N	40°N	10°N	10°–20°S	40°S	Shows increase beyond 50°S	No observed data available.
Winter								
From calculated curve	50°N(sharp and high maximum)	40°N	20°–10°N	10°S	40°S	50°S	Intensity increase beyond 50°S	Observed and calculated curves agree at low southern maximum and minimum.
From Eltanin Voyage	—	—	—	—	45°S	55°S	—	

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